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Laser Safety Features of Eye Shields

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Background and Objective: A number of lasers are available for cutaneous periorbital surgery, yet not all eye shields are appropriate for all applications. We tested a variety of commercially available eye shields to assess their safety features.
Study Design/Materials and Methods: Six commercially available eye protectors were studied. A focused laser was incident upon the shield, and the intensity and exposure duration required for visible damage to the shield were measured. We then measured the temperature on the underside of the eye shield during exposure from the laser. Time-dependent temperature measurements were made with a type-T thermocouple fixed to the eye shield with silicon grease.
Results: Thermal response curves and rates of warming for each of the six eye shields were generated. Plastic shields showed significant thermal damage with most of the lasers tested. The metallic shields warmed more slowly and to a lesser degree.
Conclusion: Overall, the metallic eye shields had the most acceptable safety profile. Many of the plastic shields exhibited significant thermal damage, and therefore we discourage their use in periorbital laser surgery.

Key words: cutaneous periorbital laser surgery, corneal protection, safety parameters, thermal response

INTRODUCTION

There has been a recent increase in the use of lasers in all areas of medicine and surgery. Laser surgery for eyelid lesions is becoming more common. Cosmetic, oncologic, and reconstructive procedures have experienced this growth both in the variety of procedures and the number of different specialists performing them. Currently, otolaryngologists, plastic surgeons, dermatologists, and ophthalmologists perform cutaneous surgery of the eyelids. The growth in laser surgery has been accompanied by extensive research regarding appropriate eye protection for operating room personnel and surgeons using lasers, yet these publications do not provide an in depth analysis of eye protection for the patient [1–6]. There are guidelines that specify the design and safety features of protective eye wear for surgeons and operating room personnel. Goggles and glasses approved for laser use must be tested and meet standards set by the American National Laser Safety Institute (ANSI) [7]. In contrast to the substantial body of information regarding protective eye wear for surgeons and operating room personnel, there is a paucity of literature available concerning safety issues of eye shields or corneal protectors worn by patients. This study is designed to augment our understanding of the safety features of eye shields worn by patients undergoing cutaneous laser surgery of the periorbital region.

One of the most common applications of lasers in periorbital cutaneous surgery is photocoagulation of periorbital vascular lesions, such as port-wine stains, hemangiomas, and telangiectasias. A number of other periorbital lesions are amenable to laser treatment, including angioma,

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Kaposi sarcoma, basal cell carcinoma, squamous cell carcinoma, blepharochalasis, neurofibromatosis, syringoma, xanthelasma, blepharopigmentation, traumatic tattoo, and nevi. This list is not exhaustive and we do not advocate laser treatment of all periorbital lesions, but rather it is an illustration of the variety of lesions for which laser surgery may be an option.

In addition to the wide variety of lesions amenable to laser treatment, a wide variety of lasers are available with which to treat these lesions. The carbon dioxide (CO_2), neodymium yttrium aluminum garnet (Nd:YAG), argon, potassium titanyl phosphate (KTP), pulsed dye, copper vapor, continuous wave dye, and ruby lasers all may be used in periorbital surgery. The list will undoubtedly expand as different wavelength lasers become available. Our study focused on four commonly used lasers: the Nd:YAG, CO_2, flash lamp-pumped dye laser (FLDL), and the argon laser. Different laser parameters were studied for each of the four lasers in an attempt to determine the appropriate eye shield for use in periorbital surgery. The factors determining appropriate eye shields include laser wavelength, multiwavelength exposure, laser fluence, maximum permissible exposure (MPE), comfort and fit, degradation potential (e.g., photo bleaching), and specular reflection. Each of these factors must be considered in selecting appropriate eye shields for laser surgery of the periorbital region.

The wavelength used will depend on the type of lesion undergoing treatment and the desired tissue effect. Different wavelengths have varied effects on substances, including the plastic and metal eye shields tested in this study. The safety of a given eye shield depends upon the interaction between the laser energy and the substance that comprises the eye shield.

There are procedures that potentially will involve multiple wavelengths. For example, treatment of a vascular lesion may include both intralesional Nd:YAG photocoagulation as well as treatment of the superficial cutaneous portion with the FLDL. The laser surgeon might also encounter a patient with two separate lesions, one amenable to excision with the CO_2 laser and one that requires coagulation with the FLDL. Eye protection for these procedures must take into account the risks associated with each of the different wavelengths used.

Laser fluence is the energy density transferred to the tissue or to the eye shield. It is measured in watt-seconds per square centimeter. It is this energy that will heat the eye shield or damage it and potentially result in injury to the globe.

Maximum permissible exposure (MPE) is defined as the level of laser radiation to which a person may be exposed without hazardous effects or adverse biologic changes to the eye or skin. This is related to wavelength and exposure time. The tissue interaction will depend on the wavelength of laser used, and the longer the exposure time the greater the effect. The American National Standards Institute (ANSI) has recently updated the published guidelines regarding MPE, and these are recommended for review [7].

Comfort is an obvious desired quality for eye shields used in cutaneous surgery of the eyelids, as many of these procedures are done with the patient awake with local anesthesia combined at times with sedation. The eye shield must fit appropriately, so as to prevent ocular injury from laser energy passing beneath the eye shield.

Degradation potential is the ability of a substance (in this case the eye shield) to change or degrade with repeated laser exposure. One example is photo bleaching, a process whereby a substance may lose pigment with repeated laser application. In the case of the blue Crouch corneal protector eye shields, they progressively became a lighter blue after repeated laser exposure. This loss of pigment will result in a loss of the protective properties of the eye shield. This process may be transitory or permanent.

Specular reflection is the material's ability to reflect laser energy. Certain metallic shields are capable of reflecting focused laser energy, which could injure the patient, the surgeon, or ancillary personnel.

A variety of commercially available eye shields and corneal protectors may be used during conventional periorbital surgical procedures. Many of these shields are not approved or intended for use in laser surgery. Inadequate corneal and ocular protection may result in visual disturbances by direct thermal damage or by transmission of laser energy to the globe. In order to avoid these injuries, adequate eye protection must be utilized during cutaneous surgery of the periorbital region. To date, there have been few studies in the literature that have evaluated the safety parameters of various commercially available eye protection devices. Initial reports urged the use of ocular protection with available standard corneal protectors, such as the Smith evaginated corneal protection shield and the Hornblass ocular protection shield, but did not critically

evaluate their safety parameters [8]. Subsequent work found these shields to be ineffective in preventing ocular injury. Summers and co-workers [9] evaluated the Smith corneal protector using cats. They directed argon laser energy at the protective eye shield and immediately after treatment performed dilated funduscopic examinations. They found the plastic corneal protectors did not prevent retinal burns [9]. Nelson and colleagues [10,11] have designed a combination polymethylmethacrylate and metal foil corneal protector that they advocate using in periorbital laser surgery. This shield was found to sustain no visible damage at low power settings, but at higher settings of the Nd:YAG and CO_2 lasers warming of the undersurface of the shield occurred, and as power settings increased further thermal damage and perforation of the eye shield occurred. The extent of the warming was a subjective qualitative assessment, determined by palpation [10,11]. This shield is not yet commercially available. Due to manufacturing problems, this shield was not available and, therefore, it was not tested in this study. We examined six different eye protection shields to characterize their safety parameters and determine their utility in laser surgery of periorbital lesions.

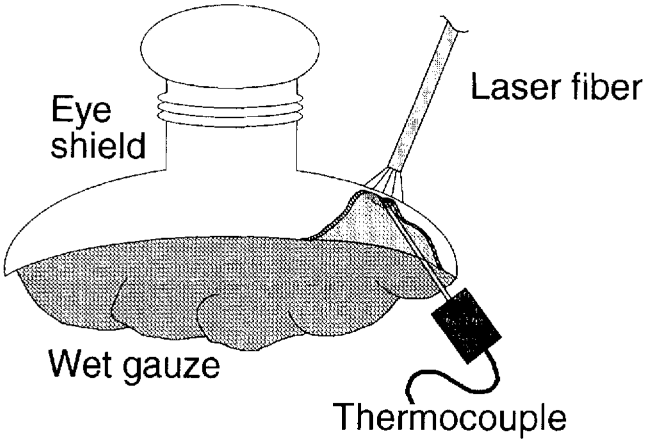

Fig. 1. Drawing of the experimental setup. The eye shield is shown with a cutaway region to show the thermocouple probe placed between the eye shield and wet gauze. The tip of the thermocouple is embedded in silicon grease for better thermal conductivity. The laser light is incident on the shield just above the tip of the thermocouple. In the case of the CO_2 laser, the beam is focused on the eye shield at this point with the hand probe.

MATERIALS AND METHODS

Six different eye protection shields were tested with four different lasers at three intensity settings. We used the Crouch corneal protectors (Storz, St. Louis, MO), red and black sclera shields (Danker Laboratories, Sarasota, FL), metallic laser eye shields (Stefanovsky, Willowick, OH), Cox Stainless Ocular Laser Shield (Oculo-Plastik, Montreal, Quebec, Canada), and commercially available white soft plastic eye protectors (sold with tanning beds). Each shield was mounted on wet cotton gauze and a type-T thermocouple (Model HYP-O, Omega Temperature, Stamford, CT) was mounted between the gauze and the eye shield (see Fig. 1). The thermocouple was on the inside (the side closest to the cornea) of the eye shields. The laser light was incident on the outside (the side away from the cornea) of the eye shields. A small amount of silicon grease (Dow Corning, Midland, MI) was used to make good thermal contact between the eye shield and the thermocouple. The thermocouple signal was amplified (Model TAC-386, Omega Temperature) and recorded by a strip chart recorder (Dash 8, Astro-Med, West Warwick, RI). The temperature was recorded at 5 kHz and the chart speed was 5 mm/s.

The Nd:YAG (Model 2100, Sharplan Lasers, Allendale, NJ) was delivered through a cleaved 600-μm fiber. The intensity delivered from the fiber was measured with a Labmaster intensity meter (Head Model #100, Coherent Lasers, Palo Alto, CA). The fiber was hand held ~1 mm from the surface of the eye shield to avoid damaging the fiber tip. The intensity was checked at the end of each experiment to make certain that the fiber was not damaged. The laser was set for the desired intensity with a 10 s duration. Temperature measurements started several seconds before the laser was turned on and continued for an additional 10 s after the laser was turned off. In all cases, the temperature dropped rapidly after the laser was turned off, but cooling was not complete in 10 s. Each new experiment was on a different section of the eye shield surface and after the eye shield had sufficient time to cool to room temperature.

The carbon dioxide laser (Sharplan 1060, Sharplan Lasers, Allendale, NJ) was delivered through a 125 mm hand probe to the eye shield. The laser intensity was measured and each exposure was on a different area of the eye shield. The 10 s exposure was timed with a stopwatch.

The flash lamp-pumped dye laser (FLDL) (Model SPTL-1, Candela, Wayland, MA) was delivered through an optical fiber and the handpiece

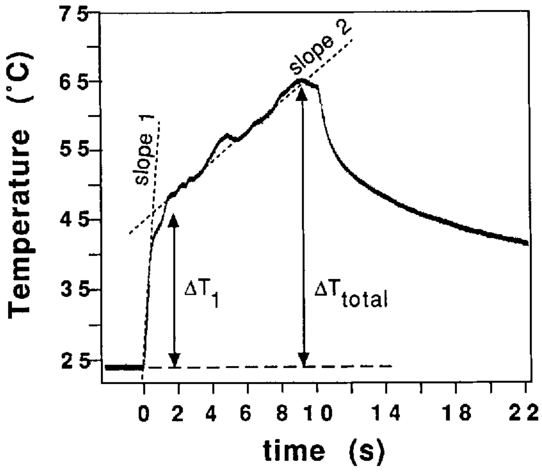

Fig. 2. Temperature of the Crouch corneal protector as a function of time. The Nd:YAG was incident at time t = 0s and left on for a 10 s exposure. The curve is labeled for the first initial temperature rise (ΔT_1) with slope 1. The second rise with slope 2 brings the temperature up to the maximum temperature increase (ΔT_{total}). After the laser is turned off the temperature begins to decrease.

that is part of the laser unit. The intensity is read from the laser display. The wavelength is set at 585 nm and the laser has a fixed pulse length of ~400 μs. Four pulses were delivered to the eye shield as rapidly as the laser would fire (once every 3 s). The laser was always fired twice after the desired intensity was set and before exposing the eye shield. This made certain that the first pulse to hit the eye shield had the expected intensity.

The argon ion laser (Model 8, HGM Laser Systems, Salt Lake City, UT) was delivered through a cleaved 400-μm fiber. Similar to the Nd:YAG laser, the intensity was checked before and after each experiment with the Labmaster energy meter (Head Model #100, Coherent Lasers, Palo Alto, CA) and the fiber was hand held ~1 mm from the eye shield surface. The exposure was timed for 10 s using a stopwatch.

RESULTS

In Figure 2, we show a typical thermal response curve, from the Nd:YAG laser incident upon the Crouch corneal protector. The initial rapid increase in temperature we termed slope 1. This rapid increase continued until a change in temperature ΔT_1. The temperature then increased at a slower rate, slope 2. The maximum temperature increase is labeled as ΔT_{total}. To accurately measure small temperature increases, the chart recorder was set to measure 20°–120°C.

The maximum increase in the temperature of the eye shield and any observed damage to the shield was recorded for each laser. These results are presented in Table 1. Once a given intensity burned through the eye shield, higher intensities were not used (to avoid damaging the thermocouple). As shown in Figure 2, the temperature typically increased very quickly and then increased at a much slower rate. In Table 2 we give the slope of the initial rapid increase (slope 1) along with the temperature rise during this first phase (ΔT_1). The slope of the slower temperature increase (slope 2) is also given in Table 2. In some instances only a single rate of temperature increase was observed. In these instances we report only one slope. If the temperature increase was >100°C, we were unable to record the full temperature profile and report only the slope of the initial temperature increase.

The carbon dioxide laser at 10.6 μm burned through or ignited a fire in all the plastic eye shields. Only the metallic eye shield remained intact. The temperature increase is amazingly small for the metallic shield. This is no doubt due to the high reflectivity. The Nd:YAG laser at 1,060 nm did not burn through the eye shields as readily. However, the temperature increases from the Storz and Danker eye shields are too large to be safe for use even on the lowest setting of the laser. The white commercial eye protectors offered reasonable protection at the lowest intensities from the Nd:YAG; however, at higher intensities the temperature increases are not acceptable. The metallic eye shield is also safe for the lowest intensity but unacceptable for the higher intensities.

If we consider the slope, or the change in temperature with time, the metallic eye shield is far safer than the commercial eye shields. The temperature rise using the Nd:YAG laser set at 6.5 W is only 1.6°C/s. The small slope means that one has time to react to a misdirected spot. This is not the case with the other eye shields and temperatures that increase at more than 10°C/s.

The FLDL at 585 nm is the only pulsed laser system tested. The temperature increases were the smallest for all of the eye shields with any laser tested. However, we note that the thermocouple showed very fast spikes in temperature using the commercial shields. The spikes in temperature were from light leaking through the white plastic. The temperature spike was ~10% of the temperature spike when the laser was directed straight at the thermocouple. We estimate, there-

TABLE 1. Maximum Temperature Increase for Different Shields With Various Lasers

	Storz blue	Eye prot. white	Danker red	Danker black	Stefanovsky metallic	Cox stainless ocular shield
Nd:YAG						
10 s						
3.0 W	ΔT = 42°C slight damage	ΔT = 9°C slight damage	ΔT = 25°C no damage	burn through	ΔT = 8°C no damage	ΔT = 10°C no damage
6.5 W	ΔT = 77°C burn through	ΔT = 56°C damage	ΔT = 67°C no damage		ΔT = 16°C no damage	ΔT = 76°C no damage
15 W	ΔT > 100°C fire	ΔT > 100°C burn through	ΔT > 100°C slight damage		ΔT = 62°C no damage	ΔT > 100°C no damage
CO_2						
10 s						
5.0 W	fire	burn through	burn through	burn through	ΔT = 0°C no damage	ΔT = 30°C marked reflection
10.0 W					ΔT = 1°C no damage	ΔT = 42°C marked reflection
20.0 W					ΔT = 5°C no damage	ΔT > 100°C marked reflection
FLDL						
4 pulses						
4.5 J/cm^2	ΔT = 4°C no damage	ΔT = 0°C no damage	ΔT = 5°C no damage	ΔT = 0°C no damage	ΔT = 0°C no damage	ΔT = 4.5°C no damage
5.0 J/cm^2	ΔT = 5°C no damage	ΔT = 0°C no damage	ΔT = 8°C no damage	ΔT = 0°C no damage	ΔT = 0°C no damage	ΔT = 6°C no damage
10.0 J/cm^2	ΔT = 11°C slight damage	ΔT = 0°C no damage	ΔT = 8°C no damage	ΔT = 5°C slight damage	ΔT = 0°C no damage	ΔT = 10°C no damage
Argon						
10 s						
2.0 W	ΔT = 23°C no damage	ΔT = 0°C no damage	ΔT = 10°C no damage	burn through	ΔT = 7°C no damage	ΔT = 30°C no damage
4.0 W	ΔT = 46°C damage	ΔT = 5°C no damage	burn through		ΔT = 15°C no damage	ΔT = 65°C no damage
8.0 W	fire	ΔT = 10°C slight damage			ΔT = 30°C no damage	ΔT > 100°C no damage

fore, that ~10% of the light was passing through these eye shields. We also tested the eye shield supplied with the laser by the Candela Corporation. They were similar to commercial shields with ~7% of the light leaking through.

The argon laser damaged the colored plastic eye shields. The temperature increase from 2–4 W on the white commercial shields was acceptable. The metallic shields are acceptable only at the lowest intensity with the argon laser.

DISCUSSION

We tested six different eye shields to determine their safety parameters according to the factors discussed above. These six shields included: (1) white eye protectors (conventional tanning goggles, sold with tanning beds), (2) blue Crouch corneal protector, manufactured by Storz, which makes no mention of laser use in the insert manual that accompanies these shields, (3) and (4) black and red scleral shields, a Danker product; the company states that these shields are not intended for laser use, (5) stainless steel Stefanovsky eye shield, (6) Cox stainless ocular shield (Fig. 3). Although most of these eye shields are not designed for laser use, they are often used by surgeons in treating peripheral eyelid lesions and therefore were included in our study.

The results of our study show that there is a maximal temperature change for each of the six eye shields tested. This temperature change may be transmitted to the cornea or globe resulting in mild to moderate injury. It may also result in thermal damage or even ignition of the eye shield, with catastrophic consequences to the patient's eye. The plastic shields were more susceptible to thermal injury with the higher power lasers. The black shields were the most unreliable, sustaining slight damage even with the FLDL. The lighter colored shields were more reliable in the visible and infrared spectra, although with mod-

TABLE 2. Rates of Temperature Increase Observed for Different Shields With Various Lasers

	Storz blue	Eye prot. white	Danker red	Danker black	Stefanovsky metallic	Cox stainless ocular shield
Nd:YAG 10 s						
3.0 W	40°/s ΔT_1 = 22°C 2.3°/s	15.6°/s ΔT_1 = 5°C 0.4°/s	8.9°/s ΔT_1 = 20°C 0.5°/s		0.8°/s	1.0°/s
6.5 W	32.7°/s ΔT_1 = 45°C 4.8°/s	24.2°/s ΔT_1 = 7°C 4.4°/s	46.7°/s ΔT_1 = 55°C 1.6°/s		1.6°/s	28°/s ΔT_1 = 76°C 2.5°/s
15 W	106°/s	60°/s	168°/s		13.2°/s ΔT_1 = 50°C 4.1°/s	>25°/s
CO_2 10 s						
5.0 W					0.0°/s	6.25°/s ΔT_1 = 25°C 1.33°/s
10.0 W					0.1°/s	4.2°/s
20.0 W					0.5°/s	43°/s
FLDL 4 pulses						
4.5 J/cm^2	0.44°/s	0.0°/s ~10% leakage	0.56°/s ΔT_1 = 20°C 0.5°/s	0.0°/s	0.0°/s	0.45°/s
5.0 J/cm^2	0.67°/s	0.0°/s ~10% leakage	0.89°/s	0.0°/s	0.0°/s	0.6°/s
10.0 J/cm^2	1.22°/s	0.0°/s ~10% leakage	0.89°/s	0.56°/s	0.0°/s	1.0°/s
Argon 10 s						
2.0 W	5.1°/s	0.0°/s	1.0°/s		0.7°/s	5.0°/s ΔT_1 = 25°C 0.67°/s
4.0 W	14.9°/s ΔT_1 = 28°C 4.6°/s	0.5°/s			1.5°/s	8.0°/s ΔT_1 = 55°C 2.0°/s
8.0 W		1.0°/s			3.0°/s	12.0°/s ΔT_1 = 60°C

erate or high energy settings sustained significant temperature change and thermal damage, especially with the Nd:YAG and the CO_2 laser.

In addition to thermal stability, another important feature of any eye shield is comfort and fit. The white commercial eye shields are not in contact with the cornea. These shields fit such that the edges are in contact with the periorbital skin. Since a misdirected laser is likely to hit the edge of the eye shield, the resultant temperature increase of these plastic shields may result in thermal injury to the periorbital skin. Although the edges of these shields are in contact with the skin at most points, variations in patients' anatomy will often result in areas where there is no direct apposition of the skin and the eye shield. In these instances, reflected laser energy may injure ocular tissues if allowed access underneath a poorly fitting eye shield. Corneal protectors must also fit appropriately and be readily placed and removed so as to avoid trauma to the cornea during application.

Testing the various eye shields with the FLDL, we found no damage with any shield, except for the Danker black shield. However, there was significant light leakage (10%) through the commercial shields. In addition, we tested the eye shields supplied with the FLDL and found a 7% leakage rate. This translates to an optical density (O.D.) of <1.2. This O.D. is far below the ANSI accepted standard of >5 O.D. for laser eye wear. We therefore question the safety of the commercial eye shields as well as those supplied with the FLDL and recommend use of the Stefanovsky

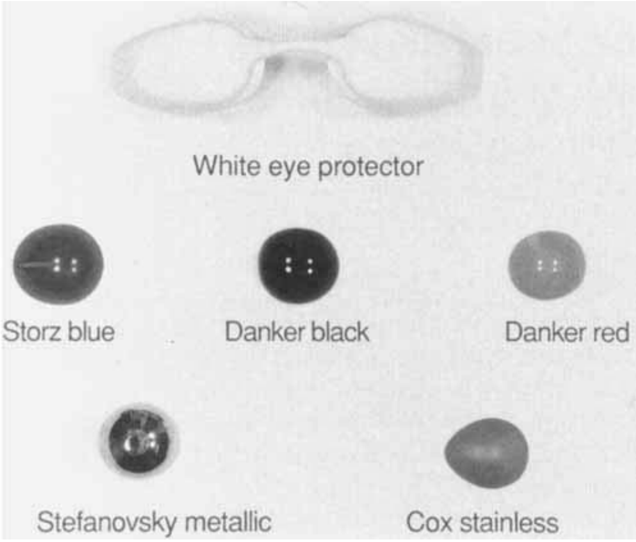

Fig. 3. Commercially available eye shields tested in this study.

metal eye shields when using the FLDL in the periorbital region.

The Cox metallic shield offers an alternative to the heavier Stefanovski shield. It has a brushed surface intended to reduce reflected laser energy. However, this shield is thinner than the Stefanovski shield and had substantial temperature increases with all lasers except the FLDL. In addition, the brushed surface is not adequate in preventing reflected laser energy. This was especially true when used with the CO_2 laser. Enough laser energy was reflected to result in a minor burn of the surgeon's hand when testing this shield. It offers some interesting potential advantages, but its safety parameters are still inferior to the Stefanovsky metallic shield. The company that developed this shield is involved in production of a sandwich-type polymethylmethacrylate and metal foil shield designed by Nelson and Pasyk at the University of Michigan [10]. This shield has some potential advantages, but we were unable to test it as it is not yet commercially available. When this shield does become available, it may add a significant improvement over existing shields, but requires further testing prior to its use in the clinical setting.

The Stefanovsky metallic eye shields seem to be the best, considering all parameters. These shields sustained no damage after testing with each of the lasers selected for study. However, there was a significant maximal temperature change with higher settings of the Nd:YAG and argon lasers (Table 1). These shields also have significant reflective capacity and should be used cautiously during procedures utilizing visible wavelength lasers. Misdirected laser energy will be reflected from the surface of these shields as a focused beam, with the potential to produce injury to the patient, the surgeon, or other operating room personnel. To address this issue, a white Teflon coating could be applied by the manufacturer that would diffusely reflect any misdirected laser energy, decreasing its potential for injury.

In summary, we recommend the use of the Stefanovsky metal corneal protectors, with the understanding that even these shields have limitations. The use of plastic eye shields and corneal protectors, especially those of darker colors, is condemned, as misdirected laser energy could potentially result in significant damage to the eye. Further research regarding improved safety parameters of the metallic shields, possibly by application of a white Teflon coating, seems prudent.

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